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Behaviour of the cathode active surface temperature in the steady-state diffuse mode of HID lamps

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1. Introduction

Generally, the topics of functioning model of high intensity discharge (HID) lamp electrode presents a big scientific interest. A lot of lamp properties and lamp efficient functioning are in strong relationship with the cathode operation. The non-linear equation of heat transfer influence the electronic emission mechanism (Schottky amplified thermionic emission, thermofield emission or field emission).

Many authors developed theoretical model in order to calculate the electrode temperature distribution [1, 2], the arc attachment modes or the transition between different mode [3].

In this paper we analyse, in the case of diffuse cathode mode functioning, the influence of some external parameters on the cathode active surface temperature.

2. Theoretical model

In the HID lamp the high value of discharge current is given by the high electron emission. This is possible by a low work emission function and by high emissive surface temperature. The second condition request a refractory material (generally tungsten), and the first condition request the material like barium or thorium deposited as a thin film on the active surface of the electrode. But, during the functioning lamp, this film is very sensitive at the sputtering and vaporisation processes trough the temperature distribution. The temperature distribution in the bulk electrode can be obtained by solving the heat transfer equation with mixed boundary conditions. These conditions modell the plasma-electrode interaction (Neuman conditions - using the heat flux continuity equation) or are imposed like Dirichlet condition (the temperature at the electrode end, or at the active emissive zone). Due to the vessel envelope blackening in the electrode vicinity, the measurement by pyrometric technique is very difficult to be carried out. For this reason we consider that any method to calculate the active surface temperature is very helpful.

In this paper we propose a method to estimate the active surface temperature and the behaviour at various external parameters changing.

The model is based on the following assumptions:

- The lamp electric discharge is considered to be in the steady-state regime;
- we suppose a lower cathode electric field ($E < 10^7 V/m$), a low pressure, a high current intensity and a weak cooling of the electrode; in this situation a lower current density is obtained and the diffuse mode is favoured [3, 4]; the attachment of the arc is very stable;
- for the electrode functioning in diffuse mode, the emissive surface cover all the front electrode surface; sometimes, a lateral part of tungsten electrode rod participate at the electric discharge (especially in the case of high pressure sodium lamps), but this case is included in our model by the increasement of active surface radius;
- all plasma - electrode interactions are in stationary regime, so, the change of surface temperature due to these interaction are unexistent;
- we suppose also that the stationary temperature distribution assure a stationary discharge current;
- we suppose that the electron current density is due to the field-enhanced thermionic emission caused by lowering of the potential barrier in the presence of an electric field (Schottky effect) (j_e^{th}) and by secondary emission by γ -Townsend process (j_e^{sec}).

The electron current density components are given by the relations:

$$j_e^{th} = AT^2 \exp\left(\frac{e\phi(E_k)}{k_B T}\right) \quad (1)$$

$$\phi(E_k) = \phi_0 - \Delta\phi(E_k); \Delta\phi(E_k) = \left(\frac{eE_k}{4\pi\epsilon_0}\right)^{1/2} \quad (2)$$

$$j_e^{sec} = \gamma_i \quad (3)$$

Here, $A = 4\pi em_e k_B^2 / h^3$ represents the

Richardson-Dushman constant, ϕ_0 is the electrode material work function, $\Delta\phi$ is the Schottky correction of work function. e and m_e represent the electron charge

respectively mass, k_B is the Boltzmann constant, h is the Planck constant, ϵ_0 is the free space permittivity and E_k is the electric field intensity in the cathode fall.

The relation of ion current density returning to the electrode (j_i), to the electron current density leaving the electrode (j_e), was determined by Waymouth [5]:

$$j_i = \beta j_e = \beta(j_e^{th} + j_e^{sec}) \quad (4)$$

The cathode field is related to the ion current density, j_i and potential drop, V_k , by the equation:

$$E_k^2 = \frac{4j_i}{\epsilon_0} \left(\frac{m_i V_k}{2e} \right)^{1/2} \quad (5)$$

with m_i the ion mass.

The magnitude of the cathode fall is somewhat larger than the mercury ionisation potential, being usually 12 – 16 V.

At the discharge current density j , we find the following equation:

$$j = \frac{1+\beta}{1-\gamma\beta} AT^2 \exp\left(-\frac{e\phi(E_k)}{k_B T}\right) \quad (6)$$

which give the electrode active surface temperature.

3. Results of the model

The model is used to calculate the active surface temperature of a d.c lamp cathode. We fix the discharge current and the value of β -Waymouth coefficient. The active surface temperature is calculated via electric field strenght. The electric field at the cathode surface is calculated from ion current density and cathode fall using Mackeon equation. The algorithm steps are as follows:

- the start with the value of total current density j , imposed by the external current discharge and electrode geometrie;
- the calcul of the ion density current $j_i = \beta j / (1+\beta)$ for a fixed β -Waymouth coefficient;
- after that, the electric fiel intensity in the cathode vicinity E_k is calculate from equation (5);
- with E_k , the electrode material work function correction $\Delta\phi$ is calculated;
- the active temperature surface is obtained with equation (6) by iterative mechanisme in order to have the total calculated current equal with imposed discharge current; the active surface temperature is ajusted until convergence.

An analysis of active temperature dependence on the front electrod radii, curent intensity discharge and β -Waymouth coefficient is caried out. The

influence of γ -Townsend coefficient on the active surface temperature is shown to be weak. Also, the active surface temperature dependence on the electrode material work function is analysed.

As example, the active surface temperature dependeces on the discharge current and on the β -Waymouth coefficient are presented in Fig. 1, respectively, Fig. 2.

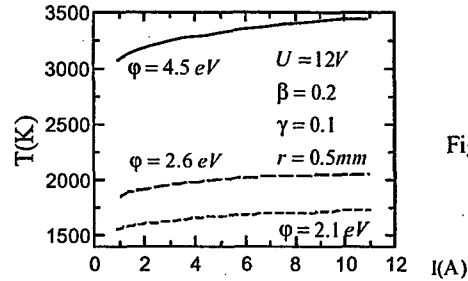


Fig.1.

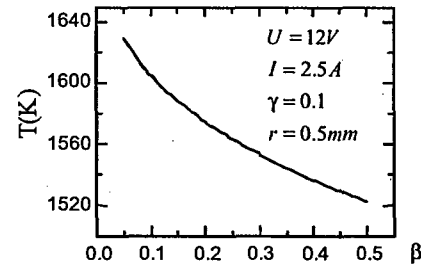


Fig.2.

This type of analysis can be extended in the case of more realistic cathode emmission. In this case, as it was shown by Coulombe and Meunier [6], is more efficient to use a tratement of Murphy and Good for electron emission instead of Richardson-Duschmann emission mechanisme corrected by Schottky effect.

But, the simplified model presented in this work, is easy to be used to give the Dirichlet condition on the top of cathode for the heat transfer equation in the cathode.

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References

- [1]. M. S. Benilov, M. D. Cunha, *J. Phys. D: Appl. Phys.* **35** (2002) 1736 – 1750.
- [2]. P. Tielemans, F. Oostvoegels, *Philips J. Res.* **38** (1983) 4-5, 214-223.
- [3]. R. Botticher, W. Botticher, *J. Phys. D: Appl. Phys.* **33** (2000) 367 – 374.
- [4]. S. Lichtenberg, D. Nandelstadt, L. Dabringhausen, M. Redwitz, J. Luhmann, J. Mentel, *J. Phys. D: Appl. Phys.* **35** (2002) 1648 – 1656.
- [5]. J. F. Waymouth, *Electric Discharge Lamps*, Cambridge, (1971), MA: MIT Press.
- [6]. S. Coulombe, J-L. Meunier, *J. Phys. D: Appl. Phys.* **30** (1997) 776 – 780.